Journal of Transport Geography 87 (2020) 102778

Contents lists available at ScienceDirect

Journal of Transport Geography

journal homepage: www.elsevier.com/locate/jtrangeo

Mobility design as a means of promoting non-motorised travel behaviour? A literature review of concepts and findings on design functions

Andreas Blitz*, Martin Lanzendorf

Goethe University Frankfurt/Main, Department of Human Geography, Theodor-W.-Adorno-Platz 6, D-60629 Frankfurt am Main, Germany

ARTICLE INFO

Keywords:
Mobility design
Built environment
Design functions
Travel behaviour
Non-motorised travel
Literature review

ABSTRACT

To promote non-motorised travel, many travel behaviour studies acknowledge the importance of the built environment to modal choice, for example with its density or mix of uses. From a mobility design theory perspective, however, objects and environments affect human perceptions, assessments and behaviour in at least three different ways: by their practical, aesthetic and emblematic functions. This review of existing evidence will argue that travel behaviour research has so far mainly focused on the practical function of the built environment. For that purpose, we systematically identified 56 relevant studies on the impacts of the built environment on non-motorised travel behaviour in the Web of Science database. The focus of research on the practical design function primary involves land use distribution, street network connectivity and the presence of walking and cycling facilities. Only a small number of papers address the aesthetic and emblematic functions. These show that the perceived attractiveness of an environment and evoked feelings of traffic safety increase the likelihood of walking and cycling. However, from a mobility design perspective, the results of the review indicate a gap regarding comprehensive research on the effects of the aesthetic and emblematic functions of the built environment. Further research involving these functions might contribute to a better understanding of how to promote non-motorised travel more effectively. Moreover, limitations related to survey techniques, regional distribution and the comparability of results were identified.

1. Introduction

With regard to the negative effects of motorised private transport, urban areas face challenges, such as congestion, air pollution and traffic noise. In order to improve conditions for local residents, many cities adopt mitigation measures, for example the implementation of car-free areas or congestion charges (Börjesson et al., 2015; Morgan and Talbot, 2000; Morton et al., 2017). Another approach relates to the promotion of sustainable transport alternatives. These involve new forms of mobility, such as sharing concepts, information technology services or electric engines, but also the promotion of non-motorised modes like walking and cycling (e.g. Banister, 2008; Lanzendorf and Busch-Geertsema, 2014; Ogilvie et al., 2007; Piatkowski et al., 2019; Pucher and Dijkstra, 2003). To promote this modal shift, a comprehensive understanding of the factors influencing travel behaviour is fundamental. Besides individual attributes, such as attitudes, perceptions, needs and resources, the design of the spatial environment is one of the decisive factors for non-motorised travel (Geurs and van Wee, 2004; McCormack and Shiell, 2011; Næss, 2005, 2015; Scheiner, 2007; van Acker et al., 2010). Urban areas comprise a broad variety of built environment objects, surrounding mobility and mobile situations (Jensen et al., 2016). 'Mobility design' involves all of these elements. From a design theory perspective, its effects on travel behaviour can be explained by means of three main functions: the practical, the aesthetic and the emblematic. The practical function pertains to the practical implementation of mobility, encompassing operation, performance and resulting travel efforts (Gros, 1972; Zeh, 2017). The aesthetic function refers to the outward appearance of the built environment evoking individual judgements on its attractiveness (Bürdek, 2015; Stamps, 2011). The emblematic function relates to the semantic content of the object representing meanings and signs (Gros, 1972; Steffen, 2000). Thus, depending on the characteristics of a built environment, design affects individual perceptions, feelings, associations and assessments.

In order to contribute to the academic discussion on sustainable mobility, the aim of this review is to examine previous research on the impact of the urban built environment on non-motorised travel behaviour in terms of design functions, seen from a mobility design perspective. We systematically selected 56 related research articles. For each of these, we assessed in detail the mobility design elements and functions, the survey method and the findings regarding the impact of

* Corresponding author.
E-mail address: blitz@geo.uni-frankfurt.de (A. Blitz).

https://doi.org/10.1016/j.jtrangeo.2020.102778
Received 14 August 2019; Received in revised form 1 February 2020; Accepted 15 June 2020
Available online 25 July 2020

the built environment on non-motorised travel. Ultimately, unlike existing reviews, we question if and how the design functions are considered in travel behaviour research studies. We also claim that the aesthetic and emblematic functions are relatively underrepresented in the analyses and discuss possible causes for this finding.

The remainder of this paper is organised as follows. Section 2 addresses the understanding of mobility design from a theoretical perspective. It starts with a spatial and social sciences understanding of design, outlines the design functions in more detail, introduces the concept of mobility design and summarises the state of the art on the impact of the built environment on travel behaviour seen from mobility design theory. Section 3 first explains the methodology of how we selected the 56 studies for this review. Next, the key findings are presented by focussing on the impact of mobility design elements and their practical, aesthetic and emblematic functions. Next, we discuss the findings in the light of the theoretical framework and identify five shortcomings of previous research (section 4). The paper ends with some conclusions (section 5).

2. Understanding mobility design

2.1. Design from a spatial and social sciences perspective

Throughout its history, the understanding of design has been subject to several transition processes and it still is today. Deriving from Latin, the term originally describes the process of giving significance to an object by assigning it to a purpose or user (Krippendorff, 2006). Initially used to describe a draft or a plan devised by a person for a certain type of work, the concept of design has been associated with the industrial production of goods since the 19th century (Bürdek, 2015; Mareis, 2011). Meanwhile, Mitchell (1993, p.64-65) characterises design as "the process of devising not individual products but whole systems or environments such as airports, transportation, […] computer networks" and even as an activity "without a product, as a process or way of living in itself". Therefore, not every designed object arises in a physical form. Design rather involves the development and operation of all artificial, man-made things, material goods as well as services, procedures, rules and organisational structures (Norman, 2013).

Until the middle of the 20th century, theoretical approaches to design and the design process itself were determined by the paradigm of functionalism (Bürdek, 2015). Louis Sullivan's (1896) well-known dictum "form follows function" describes the underlying principle of a design idea, which has to be derived from the purpose and practical features of an object, primarily entailing unpretentious and sober works (Krippendorff, 2006; Mareis, 2014). Arguing mandatories, rationality and inadequacy of aesthetics, criticisms of functionalism evolved in the last decades, putting forth the inclusion of the user's perspective in design processes (Mareis, 2014). As a result, the concepts of 'human-centred design' emerged, relating to the objective of meeting people's demands by means of design activity. They focus on the interaction between users and objects, considering the perceptual, cognitive and emotional needs of the person addressed (Giacomin, 2015).

Design research from a social sciences perspective focuses on the effects of designed artefacts on the user's behaviour – usually identified by personal and focus group interviews, surveys or monitoring – mainly taking individual, social and cultural implications into account (Giacomin, 2015; Mitchell, 1993). Norman (1988) involves psychological approaches on human behaviour to provide an understanding of the interrelation between user and design objects. By referring to Gibson's (1979) ecological approach to perception, he describes these interrelations as 'affordances', which "represent the possibilities in the world for how an agent (a person, animal, or machine) can interact with something" (Norman, 2013, p.18). In this context, behaviour is defined by the object's properties and quality as well as by the agent's abilities and perceptions. So-called 'signifiers' give an indication of the purpose and handling of an object, e.g. signs on doors labelled "push", and are therefore significant elements of design.

2.2. The functions of design objects

Other approaches to the interaction between objects and users highlight the communicative functions of design (Bürdek, 2015; Krippendorff, 2006). In their work on 'product semantics', Krippendorff and Butter (1984) stress the object's transmission of messages, related to its usage and its social and cultural meanings. They point out the importance of these symbolic qualities of design set by its form, shape, texture, markers and information displays as well as its technical specifications and its context of use (Demirbilek and Sener, 2003). The user acts as a receiver decoding the object's messages by means of sensory perception, responding on the basis of individual evaluations, emotions and previous experiences (Crilly et al., 2004). Thus, today's understanding of design theory and practice refers to the idea of endowing meanings to objects or in other words "making sense of things" (You and Kuohsiang, 2003).

Based on the works of the linguist Mukařovský, Gros (1972) proposes a model of functions related to human needs and activities to describe the communication between object and user. Involving semiotic meanings as well as practical values, he discerns three main types of design function: (i) the practical, (ii) the aesthetic and (iii) the emblematic function (Bürdek, 2015; Gros, 1972). Firstly, the practical function refers to the execution of the purpose of the object and its utility comprising operation, durability and safety. It primarily addresses the physiological needs of the user, for instance travel, clothing or feeding (Gros, 1972). In this context, the design object takes effect by serving as a tool for implementing a certain task or enabling a certain action. The assessment of the practical function is based on the object's operational performance, involving effectiveness, efficiency, expediency, time requirement and work capability (Zeh, 2017).

Secondly, the aesthetic function relates to the formal and aesthetic qualities of the object that are perceived separately from possible underlying meanings and interpretations (Bürdek, 2015; Mareis, 2014). It includes the object's form, look, structure, materials, colours and visualisation evoking judgements on its attractiveness or beauty, triggering positive or negative feelings of pleasure or unpleasantness (Stamps, 2011). Although these judgements depend on the user's subjective experiences and preferences, within design theory a variety of objective principles was established to which related effects are attributed (Crilly et al., 2004). These comprise similarity, proximity, closure, symmetry, conciseness as well as complexity and order of objects (Zeh, 2017).

Thirdly, the emblematic function refers to semantic content and the information conveyed by the design object. Gros (1983) describes this function by differentiating 'symbolic' and 'signifier' functions, evoking either certain associations or illustrating the practical features of the object. The former indicate meanings based on cultural conventions representing social, technological, economic or ecological contents, for instance concerning individual preferences or class affiliation (Bürdek, 2015; Mareis, 2014). This symbolic function primarily affects the user's desires for social standing and self-realisation, as well as the need for safety, which is also influenced by subjective associations (Gros, 1972). The signifier function points to the purpose and current state of the object or explains its utilisation, prompting interaction with the object in a particular way, similar to Norman's (2013) notion mentioned above. Thus, signifier elements directly make the object's practical function perceptible and intelligible (Steffen, 2000). For example, the slide switch on a lamp indicates the lamp's operation, its current adjustments and the presence of different light levels.

Practical, aesthetic as well as emblematic elements trigger human cognitive processes, such as information reception, emotions, attitudes, assessments and motivations. Thus, the model of design function refers to features of a product that go beyond commonly evaluated characteristics, such as costs or durability. The design elements evoke or influence certain behaviour and are critical for the usage and success of designed artefacts (Crilly et al., 2004; Godau, 2003; Mayer, 1996; Zeh, 2017). Within this process the three functions of an object act simultaneously and interdependently (Gros, 1972; Schwer, 2014). Although one function may be dominant for a certain design feature, the others might have an impact on the user's perceptions as well. For instance, an element's colour and structure affect a person's emotional state but at the same time associations with certain lifestyles or social groups may arise (Crilly et al., 2004; Demirbilek and Sener, 2003). In order to evaluate an object's impact on the user's behaviour and to explain its significance, therefore, all of its functions need to be considered and addressed specifically. In doing so, the overall impressions impinging on the user can be identified and distinguished. As the model of design functions provides a meaningful basis for characterising design effects as well as for implementing design processes, the approach has gained attention in recent years (Schneider, 2005).

2.3. Mobility design and travel behaviour

Within the field of mobility, design may refer to a broad variety of objects and systems, enabling and surrounding the movement of individuals (Edelmann, 2007). Therefore, mobility design includes not only vehicles, infrastructures and services, but also public spaces of mobility as well as their associated environments. Rammler (2011) broadens the understanding of mobility design even more by claiming its importance within transport policy and planning. He discerns three forms of design innovation that facilitate sustainable and user-friendly travel behaviour (Rammler, 2003, 2011): product modifications (e.g. engine technology), usage innovations (e.g. carpooling or bike sharing) and system innovations (e.g. digital infrastructures). Jensen et al. (2016, p. 27) define 'mobilities design' in the context of the individual experience of mobile situations as "the nexus between design (architecture, urban design, service design, etc.) and mobilities". Relating to Gibson's term of affordances of the environment, Jensen et al. argue that "the mobile subject cannot be separated from materialities such as infrastructures, places and routes, technologies such as transportation modes, GPS systems, mobile phones and other things […] that are brought along on everyday journeys" (Jensen et al., 2016, p. 32). In this way, design refers to an environment's objects and setting surrounding mobile situations. By providing sensory impressions on the basis of the objects' characteristics, such as surface, colours, volumes or densities and their combined effects, design impinges on human perceptions and actions, affording, enabling or preventing mobility (Jensen, 2014). In our understanding, mobility design concerns all of these objects whose impact on travel behaviour can be explained by communication and interrelations due to their design functions.

Mobility design involves a broad variety of elements in public spaces within which mobility takes place. In recent years, there has been an increasing amount of empirical research referring to travel and the design of these environments. In urban areas, design typically relates to the physical elements of a city, considering their appearance and arrangement by involving several disciplinary approaches in the design process, such as architecture, planning and engineering. Thus, urban design sets the city's physical form, characteristics and image (Arida, 2007; Frey, 1999; Handy et al., 2002). These physical elements are usually described by the term 'built environment', including a wide array of objects, ranging from small, local scale structures, such as park benches and pavements, to the layout of entire streets, neighbourhoods or cities (Cervero and Kockelman, 1997; Lawrence and Low, 1990; Siebertz, 2007). Previous findings indicate an impact of built environment features on individual travel behaviour, also concerning non-motorised modes (see e.g. Brownson et al., 2009; Cervero, 2003; Ewing and Cervero, 2010; Litman and Steele, 2018; Næss, 2005; Saelens and Handy, 2008; Smith et al., 2017; Wegener and Fürst, 1999). Individual perceptions of design and its functions are related to the way and speed of moving (Ewing and Clemente, 2013; Stamps, 2011). Hence, walking and cycling behaviour may be associated with elements other than motorised means of transport, entailing particular research objects and concepts (Johansson et al., 2016; Oliver et al., 2013; Pikora et al., 2003; Simpson, 2017).

Much of travel behaviour-related research on design impacts addresses the practical design function based on the traditional utility theory (Bohte et al., 2009). Relevant studies suggest that travel behaviour is based on the maximisation of utility that can be obtained by choosing a certain mobility option. In that respect, the built environment contributes to the utility by setting the effort (e.g. time requirements, financial expenditure and physical conditions) for reaching a destination (Maat et al., 2016). Therefore, practical elements pertain to the enablement and facilitation of mobility, involving costs, efficiency, expediency, reliability, safety and simplicity of travel alternatives in public space. Related to non-motorised travel, in particular the distances between origin and destination, the presence of coherent routes, safe paths and crossings, as well as the absence of barriers, define practicability (Brownson et al., 2009; Timms and Tight, 2010). Within the much-noticed work of Cervero and Kockelman (1997), the authors point out three dimensions ("3Ds") of the built environment affecting travel behaviour, primarily by means of the practical function. These include *density* of population and employment, *diversity* of land use and *design* concerning the street network pattern and provision for pedestrians and cyclists. Data from studies relating to these dimensions mostly suggest that high street connectivity (depending on intersection densities and block lengths), high pavement coverage, mixed land use and a high density of facilities, such as workplaces, shops, dwellings and cultural institutions, improve the accessibility of everyday activities. As more destinations are reachable within short distances, time requirements and physical efforts decrease, encouraging people to travel on foot or by bike and reducing car usage (Banister and Hickman, 2006; Ewing and Cervero, 2010; Holtzclaw, 1994; Næss et al., 1996; Næss, 2012; Newman and Kenworthy, 2006; van Wee, 2002). Until now, further dimensions were added to the "3Ds" approach, also comprising the practical variables of *destination accessibility* and *distance to transit* (Ewing and Cervero, 2010). However, some authors argue about the similar impacts of the selected dimensions and their mutual dependency as well as the lack of aesthetics as a research subject (Handy, 2018).

Other publications point out the importance of the qualities of public spaces involving comfort-related design objects (e.g. seating, lighting, weather protection) as well as rather subjective and individually perceived aesthetic characteristics concerning architectures, greenery, decorations, fabrics and metrics of built forms (Bohte et al., 2009; Ewing and Clemente, 2013; Johansson et al., 2016; Pikora et al., 2003; Saelens et al., 2003). These aesthetic qualities "contribute to the attractiveness or appeal of a place" (Handy et al., 2002, p. 66), defining people's impressions and experiences (Timms and Tight, 2010) and, thus, go beyond the factors of traditional utility theory. Within design research, the aesthetic function of the environment is associated with emotional effects based on the individuals' judgement of attractiveness and beauty. Thus, surroundings may evoke feelings of well-being, pleasure or arousal, influencing individual assessments and spatial behaviour (Franz and Wiener, 2008; Nasar, 1992; Stamps, 2011). For instance, several studies point out the affective impacts of vegetation and greenery reducing feelings of stress, anxiety and fear, while fostering elation and pleasure (Smardon, 1988; White and Gatersleben, 2011). In his work "Cities for people", Gehl (2010) emphasises the importance of aesthetic design features contributing to a liveable, healthy and sustainable environment by taking human needs into account.

Moreover, Gehl (2010) addresses the emblematic function of public spaces, for example representing places, which are democratic, social or inviting to active transport. From the design perspective, "physical elements of the environment do encode information that people decode" (Rapoport, 1990, p. 19). Therefore, architectural components, such as decorative elements, facades, colours, materials, may be associated with certain contents, such as time periods, social group identities, values or statuses (Lawrence and Low, 1990). But also the urban form of a city indicates meanings, such as egalitarianism (represented by equal structures and architectures), recreation (detached buildings and parks) or crime (narrowing, complex and darkening structures) (Nasar, 1992; Rapoport, 1990). Even though the same mobility design elements may evoke different associations and feelings due to individual experiences, perceptions and preferences, it is commonly assumed that aesthetics and comfort features influence walking and cycling behaviour, at least in terms of route choice (Bhat et al., 2000; Flade, 2013; Johansson et al., 2016; Næss, 2005; Pikora et al., 2003).

As noted before with regard to the model of design functions, design elements, including those of public space, might embody two or three functions at the same time influencing each other (Crilly et al., 2004). For instance, Rapoport (1990) stresses the aesthetic importance of greenery within public space arousing feelings of satisfaction but also communicating meanings of high environmental quality, order, harmony and privacy, whereas the reduction of greenery, littering or graffiti may evoke negative feelings as well as represent signs of social disorder and crime (see also Nasar, 1992; White and Gatersleben, 2011). The latter may be associated with poor road surfaces as well, also indicating declining practical usability. Although significance concerning travel behaviour within public space is attributed to each of the three design functions, previous reviews of the interrelation between built environment elements and travel behaviour show that aesthetic and emblematic features have however gained little attention within mobility research papers and academic discussion (cf. Crane, 2000; Ewing and Cervero, 2010; Frank and Engelke, 2001; Saelens and Handy, 2008). The comprehensive meta-analysis of Ewing and Cervero (2010) reveals the emphasis on street network characteristics and destination accessibility, in particular addressing the practical function. In the following, we enlarge upon studies that were published since this review by Ewing and Cervero, focusing on recent research and pointing out practical, aesthetic and emblematic functions equally.

3. Mobility design functions in studies on the built environment and non-motorised travel

Within this section, we provide an analysis of recent findings on the impacts of mobility design on non-motorised travel behaviour in urban environments, discussed from a design theory perspective. In contrast to previous reviews, we examine which of the three design functions are taken into account and what corresponding effects can be investigated. We refer to the results of empirical studies by assigning design elements involved to the practical, aesthetic or emblematic function.

3.1. Methodology of the review

The search of relevant articles has been made in accordance with the aim of examining recent research concerning the effects of urban built environment design on non-motorised travel behaviour. In order to meet the criteria, the selection of studies is based on the 'Web of Science' searching tool, including matches which contain the terms "design" and "built environment" and "travel behaviour" or "travel behavior" as well as "urban", "city" or "cities" within the title, abstract or key word list. We restricted our selection to articles published since Ewing and Cervero's (2010) meta-analysis on "Travel and the Built Environment". Although this meta-analysis may not have covered all studies up to that point due to an emphasis on the approach of "3Ds", we refer to the period afterwards in order to focus on recent research and not to repeat the work done by then. The search within the nine-year period resulted in 148 matches. Subsequently, studies that proved to be incompatible in terms of the research aim were excluded. These comprise 32 papers on topics other than travel behaviour, like health and medicine (8), energy consumption (7) or economics (2). Thirteen of the remaining articles revealed no case study research of their own. As we are interested in findings related to the promotion of non-motorised modes within western societies, ten studies on car or public transit only and 37 studies on non-western regions were excluded as well. Thus, 56 studies remained for our analysis (Table 1).

For each study, we examined in depth the design elements' functions taken into account as well as the relevant survey method, data information, dependent variables and observed results. The results listed in Table 1 involve findings on mobility design elements that are stated by the respective authors as encouraging an increase in non-motorised travel. Since the results are based on different investigation methods, these include both quantitative (e.g. statistical models) and qualitative analyses. We describe the survey methods of mobility design elements taken into account within the studies by means of three different categories. Studies assigned to "respondent's perceptions" derive their data on the design elements' presence and characteristics directly from the study's participants (e.g. by inquiring which design elements surround or affect them). "Author's observations" refer to design elements observed by the authors (e.g. by mapping the built environment's elements of a certain neighbourhood). Studies assigned to "secondary data" include design element information based on georeferenced parcel data, census data or image recordings neither inquired from survey participants nor observed by authors.

We discern four main types of mobility design elements taken into account within the studies: (i) land use, (ii) street network, (iii) walking and cycling facilities and (iv) public space qualities. These are derived from the analysis of the selected studies as well as from previous typologies (section 2.3). The following guidelines were adopted for the elements' classifications: Elements related to land and building development assigning certain activity options to a piece of land were attributed to the land use type. Examples include dwellings, shops, schools, factories and parks representing residential, commercial, industrial, educational or leisure destinations (Næss, 2015). The presence and distribution of land use, e.g. identified by its proximity, density and diversity, determine the accessibility of activities with regard to distances, affecting travel efforts, in particular travel time and costs (van Wee, 2002). Those elements pertaining to the arrangement of streets and intersections, providing connectivity and routes between origin and destination, were assigned to street network characteristics. Amongst others, these include street lengths and types, node distributions and block sizes. Walking and cycling facilities are directly assigned to non-motorised modes. They concern the infrastructure for walking and cycling and its characteristics, comprising footpaths, pavements, cycle paths or bike parking spaces. Public space qualities refer to public micro-scale features, amenities and aesthetics, setting the atmosphere and attractiveness of a place. They cannot be associated directly with certain activities, route connectivity or traffic infrastructures. They include more perceptual qualities, such as facades and architectures, but also obvious features, for example the arrangement of buildings and the presence of street furniture, lighting or trees. This typology of mobility design elements provides a good overview of the research focus of the studies and facilitates the identification and systematic discussion of the three design functions.

To identify and distinguish the design functions addressed, we have investigated how the effects of the design elements taken into account were evaluated in the respective study: either in terms of travel efforts, aesthetic perceptions or evoked associations. Evaluations of the mobility design's impact on travel efforts, such as measurements related to travel distances or route directness were assigned to the practical function (P). These include in particular assessments of factors discussed in utility theory research (section 2.3). Studies referring to the effects of aesthetic features on walking and cycling, for instance those which investigated feelings evoked by the surrounding architecture of buildings, were attributed to the aesthetic function (A). Investigations on travel behaviour affecting associations evoked by mobility design elements, for example the impact of associations with insecurity, were

Table 1
Practical, aesthetic and emblematic functions, design element types and survey characteristics of the selected studies for mobility design and non-motorised travel.

Study	Mobility design elements							Travel behaviour	Data					Results
Author(s) (year)	Type(s) and related function(s) P: practical A: aesthetic E: emblematic				Survey method(s)			Dependent variable(s)	Source	N	Sample	Year	Country	Elements increasing non-motorised travel
	Land use	Street network	Walking / cycling facilities	Public space qualities	Author's observations	Respondent's perceptions	Secondary data *							
Aguiléra and Voisin (2014)	P						X	- mode choice	French Population Census	n. m.	residents from 26 municipalities	2007	France	- job density, population density
Appleyard (2012)	P	P	P	A			X	- mode choice	BART Station Profile Survey	5694	random sampling	2008	USA	- land use diversity - route directness - bike parking spaces - small parcel size
Appleyard and Ferrell (2017)	P	P	P				X	- transit access mode choice	BART Station Profile Survey	2686	random sampling	2008	USA	- mixed use entropy, proximity to station - intersection density - bike parking spaces
Badland et al. (2012)	P	P					X	- work-related mode choice	Understanding the Relationship Between Activity and Neighbourhoods study (URBAN)	1616	employees living in 48 selected neighbourhoods (aged 20-65)	2008-2010	New Zealand	- walkability (dwelling density, land use diversity, retail floor area ratio, intersection density)
Banerjee and Hine (2014)	P	P	P			X		- mode choice	own survey	35	residents from 3 case study areas as well as "experts"	2013	UK	- population density - low road density - public transit services
Barnes et al. (2016)	P						X	- modal split of one month	Canadian Community Health Survey-Healthy Aging (CCHS-HA)	3860	residents of private dwellings (aged 45+)	2008-2009	Canada	- Walk Score (proximity along the street network to amenities) - Transit Score (proximity to the nearest transit stop, high frequency of service)
Battista and Manaugh (2018)	P		P	A, E		X		- walking behaviour	own survey	30	residents living at least 6 months in the neighbourhood	2016	Canada	- proximity to amenities - pleasurability of architecture, perceived safety of public space built environment, spatial familiarity
Berrigan et al. (2010)		P					X	- propensity of walking or cycling for transport - average time spent walking or cycling	California Health Interview Survey (CHIS)	10389	random sampling	2001	USA	- short blocks, dense nodes (grid-like structure)
Cho and Rodríguez (2015)	P, A	P					X	- taking a walking trip on a designated day	National Household Travel Survey (NHTS)	1183	random sample (aged 15+)	2008-2009	USA	- highly urban neighbourhoods (proximity to main core area, rail stations, highway; density of jobs, density of parks) - highly walkable (density of population, households, employment, retail service jobs, roads, ratio of 3-way and 4-way intersections, park area)
Cui et al. (2014)	P	P					X	- number of bicycle trips per day	Household Travel Survey (HTS)	14365	random households	2007-2008	USA	- population and household density, office land use, access to transit - low motorway length

(*continued on next page*)

Table 1 (*continued*)

Study	Mobility design elements							Travel behaviour	Data					Results
Author(s) (year)	Type(s) and related function(s) P: practical A: aesthetic E: emblematic				Survey method(s)			Dependent variable(s)	Source	N	Sample	Year	Country	Elements increasing non-motorised travel
	Land use	Street network	Walking / cycling facilities	Public space qualities	Author's observations	Respondent's perceptions	Secondary data *							
Curl et al. (2018)	P	P					X	- frequency of walking trips lasting 20 minutes within one week	GoWell study	1063	residents in 15 deprived areas	2011, 2015	UK	*no significant results*
de Vos et al. (2018)	P	P					X	- mode choice - mode frequency	own survey	1539	recently relocated residents	2017	Belgium	- urban neighbourhood (density of population and buildings, land use diversity; intersection density, small building blocks)
Ewing et al. (2013)	P	P					X	- likelihood of walking	six regional household travel surveys	35877	trips within one of 239 mixed-use developments	1991-2001	USA	- land use diversity, high number of residents and jobs, job-population balance, access to jobs - intersection density
Frank et al. (2015)	P, A	P		A, E		X	X	- number of walking trips lasting 10 minutes or longer within one week	Urban Design 4 Health	2748	random sample (aged 25+)	2011	Canada	- perceived walkability (land use diversity and density, proximity to shops and services, proximity to green space, small lot sizes) - objectively measured walkability (net residential density, retail/ commercial floor area ratio, land use diversity, intersection density)
Gehrke and Clifton (2014)	P						X	- mode choice	Oregon household activity survey	4183	home-based social and recreational trips	2010	USA	- land use diversity, population density
Gehrke and Welch (2017)	P	P					X	- walk mode choice of work-based sub-tours	Oregon Household Activity Survey	655	work-based sub-tours	2011	USA	- population density, low employment entropy - block density
Giles-Corti et al. (2013)	P, A	P	P	A, E		X	X	- minutes of walking in a usual week within the neighbourhood	Residential Environment Study (RESIDE), Neighbourhood Physical Activity Questionnaire (NPAQ)	1420	people who moved into one of 73 new housing developments	2005-2006	Australia	- walking destinations, access to mixed use and services, access to parks - no/few cul-de-sacs, intersection density - footpaths on most streets, infrastructure providing safety for walking, no barriers - perceived neighbourhood aesthetics, associations with safety
Gunn et al. (2014)			P		X			- number/duration of walks per week	Study of Environmental and Individual Determinants of Physical Activity (SEID I/ II)	1394	random sample (aged 18-59)	1995-2000	Australia	- adequate pavement condition status
Hajrasouliha and Yin (2015)	P	P, A					X	- number of pedestrians	State University of New York at Buffalo	302	street segment pedestrian counts	2007-2010	USA	- land use diversity, job density - intersection density, visual integration

(*continued on next page*)

Table 1 (*continued*)

Study	Mobility design elements							Travel behaviour	Data					Results
Author(s) (year)	Type(s) and related function(s) P: practical A: aesthetic E: emblematic				Survey method(s)			Dependent variable(s)	Source	N	Sample	Year	Country	Elements increasing non-motorised travel
	Land use	Street network	Walking / cycling facilities	Public space qualities	Author's observations	Respondent's perceptions	Secondary data *							
Helbich (2017)	P	P	P	A			X	- modal choice for trips to school	own survey	97	children (aged 6-11)	2008-2009	Netherlands	- low land use diversity - low 3-way and >4-way intersection density, accessible street network
Hirsch et al. (2016)	P						X	- daily step count	Walk the Talk (WTT)	77	older adults with low income (aged 65+)	2012	Canada	- diversity of destinations, density of convenience stores and banks
Hong et al. (2014)	P	P					X	- VMT	Household Activity Survey	2564	random sample	2006	USA	- land use diversity, residential density, non-residential density, proximity to bus stop, proximity to central business district - intersection density
Hong et al. (2016)	P						X	- walking frequency - minutes of active travel	Expo Line study	277	residents living within 1/2 mile of a new station, individuals of a control group	2011-2013	USA	- proximity to transit
Joh et al. (2012)	P	P					X	- number of walking trips within one day	South Bay Travel Survey	2125	residents in eight neighbourhoods	2005-2007	USA	- nearby walking destinations - intersection density
Kamargianni (2015)			P			X	X	- mode choice, mode choice preferences - frequency of cycling	own survey	9544	adolescents in public high schools	2012-2013	Greece, Cyprus	- bike parking facilities, cycle lanes, cycle paths, wide pavements
Kamruzzaman et al. (2016)	P	P				X	X	- time spent walking for transport within one week	How Areas in Brisbane Influence Health and Activity (HABITAT)	3708	random sample (aged 40-70)	2009-2011	Australia	- residential density, access to train station within 10 min. (perceived) - street connectivity, 3/4-way intersection density
Kim et al. (2018)	P	P	P				X	- mode choice	National Household Travel Survey (NHTS)	751	trip destinations	2008-2009	USA	- density of population and employment, land use diversity, land use entropy - length of bicycle facilities
Knuiman et al. (2014)	P	P				X	X	- frequency of neighbourhood walking within one week	Residential Environment Study (RESIDE)	1813	adults within 73 new housing developments	2005-2012	Australia	- land use diversity, proximity to bus stops and railway stations, access to different types of destinations - street connectivity
Koohsari et al. (2013)	P, A	P	P	A, E		X	X	- frequency and duration of walking to and within public open spaces within one week	own survey	335	residents from three diverse neighbourhoods	2011	Australia	- facilities for walking - perceived aesthetics, perceived safety
Lamíquiz and López-Domínguez (2015)	P	P, A					X	- percentage of walking trips	Regional Mobility Home-Based Survey	96000	trips in 150 urban areas	2004	Spain	- density of residents, jobs, students and food units, diversity of food units, jobs/residents ratio - configurational accessibility of the street network

(*continued on next page*)

Table 1 (*continued*)

Study	Mobility design elements							Travel behaviour	Data					Results
Author(s) (year)	Type(s) and related function(s) P: practical A: aesthetic E: emblematic				Survey method(s)			Dependent variable(s)	Source	N	Sample	Year	Country	Elements increasing non-motorised travel
	Land use	Street network	Walking / cycling facilities	Public space qualities	Author's observations	Respondent's perceptions	Secondary data *							
Larco et al. (2012)	P	P	P			X	X	- number of bike and walking trips - percentage of all trips that are active (bike or walking)	own survey	191	households near shopping areas within 14 apartment developments	n. m.	USA	- perceived ease of walking and biking in the neighbourhood - pedestrian-friendly environment (route directness, street type. protected pedestrian paths)
Lee (2016)	P	P					X	- mode choice	National Household Transportation Survey of Los Angeles County (NHTS-CA)	4231	random sample (aged 16+)	2009	USA	- residential density, land use diversity; proximity to retail stores, access to transit - street connectivity
Lee et al. (2013)	P	P	P				X	- frequency of walking within one week	own survey	933	55-65 year-old baby boomers	2010	USA	- land use diversity, access to retail, open space density, net floor-area-ratio - intersection density
Lee et al. (2017)	P	P					X	- short tour mode choice	National Household Transportation Survey of Los Angeles County (NHTS-CA)	4231	random sample (aged 16+)	2009	USA	- land use diversity, retail employment density - street connectivity
Lindelöw et al. (2017)	P	P	P		X	X		- number of walking trips per week	own survey	1001	adults within 3 neighbourhoods	2011	Sweden	- fine-grained urban fabric, integrated street network
Liu and Shen (2011)	P	P					X	- mode choice - VMT	National Household Travel Survey (NHTS)	372	random sampling	2001	USA	- population density
Marquet and Miralles-Guasch (2015)	P						X	- mode choice - number of minutes spent walking	Everyday Mobility Inquiry	12019	random sample (aged 65+)	2006	Spain	- population density, urban land use distribution
McConville et al. (2011)	P, A		P				X	- transportation walking time within one week	own survey	260	adults capable of walking	2004-2006	USA	- proximity to destinations to meet daily needs, to be physical active; density of bus stops, grocery shops, offices, retail shops; diversity of destinations
McCormack et al. (2017)	P						X	- change in walking / cycling for transportation	Physical Activity, Health and Demographic Questionnaire (PAHDQ)	915	random sample (aged 20+)	2014	Canada	- walk score (straight line proximity to nine common amenities)
Milakis et al. (2017)	P, A		P	A, E		X		- change in driving, walking and cycling after relocation	own survey	51	Greeks who relocated from the USA to Greece	n. m.	Greece	- access to shopping centre, to public transport and to other local amenities - good cycling facilities - nice architectural design of residential/ civic buildings, street furniture, perceived safety of biking conditions

(*continued on next page*)

Table 1 (*continued*)

Study	Mobility design elements							Travel behaviour	Data					Results
Author(s) (year)	Type(s) and related function(s) P: practical A: aesthetic E: emblematic				Survey method(s)			Dependent variable(s)	Source	N	Sample	Year	Country	Elements increasing non-motorised travel
	Land use	Street network	Walking / cycling facilities	Public space qualities	Author's observations	Respondent's perceptions	Secondary data *							
Mitra et al. (2015)	P, A	P	P, E	P, A, E		X	X	- walking behaviour	own survey	14	capable walkers (aged 65+)	2013	Canada	- proximity to shops, retail outlets and strip malls; proximity to parks and the natural environment - no cul-de-sacs - pavements on both sides of the street; maintenance of pavements and no physical obstructions; gradual curb at intersections; traffic lights and pedestrian signals matching the walking speed - benches, trees providing shade, street lights, security cameras; parks, nature trails, woodlands, gardens, nice scenery, fountains
Moniruzzaman and Páez (2012)	P, A	P	P	P, A	X		X	- walking mode share for the journey to work	Canadian Census	343	street segments within 20 Census areas	2006	Canada	- land use diversity, dense greenery - street connectivity, 4-way intersections - complete pavements, traffic control devices, crossing aids, bike facilities - amenities, trees, small setbacks, multi-floor buildings
Moniruzzaman et al. (2013)	P	P					X	- walking mode share - walking trip length	Montreal's Household Travel Survey	31631	home-based trips by senior cohorts (aged 55+)	2008	Canada	- land use diversity, high share of building square footage - street density/lengths
Noland and DiPetrillo (2015)	P	P		E		X	X	- mode choice - walking frequency	own survey	1629	random households in or near 8 locations with rail transit	2012	USA	- proximity to train station, transit-oriented developments - dense local street network
Olaru et al. (2011)	P	P	P		X			- trips by mode - daily travel time - daily travel distance	own survey	1034	random sampling	2010	Australia	- population and dwellings density, proximity to public transit - quality of cycling/pedestrian facilities
Ramezani et al. (2018)	P	P	P	P, A	X		X	- mode choice	own survey	524	adult residents of 17 urban areas	2013	Italy	- land use diversity, access to transit - integrated local street network - public space qualities (wide pavements. street lighting, planted strips, flat terrain, windows and doors opening onto street, pedestrian crossings)
Rybarczyk and Wu (2014)	P, A	P, A	P				X	- number of walking/ bike trips per month	National Household Travel Survey (NHTS)	6210	random sample	2001-2002	USA	- population density, proportion of renter-occupied housing - low visual entropy, visual integration, potential for visual change

(*continued on next page*)

Table 1 (*continued*)

Study	Mobility design elements							Travel behaviour	Data					Results
Author(s) (year)	Type(s) and related function(s) P: practical A: aesthetic E: emblematic				Survey method(s)			Dependent variable(s)	Source	N	Sample	Year	Country	Elements increasing non-motorised travel
	Land use	Street network	Walking / cycling facilities	Public space qualities	Author's observations	Respondent's perceptions	Secondary data *							
Simons et al. (2017)	P					X		- mode choice	own survey	1307	emerging adults	2013	Belgium	- urban neighbourhood (within suburb or city)
Stevens and Brown (2011)	P	P	P		X			- accelerometer-measured moderate-to-vigorous physical activity	own survey	187	fifth graders in 11 classes at two schools	2007	USA	- walkability (land use density and diversity, small lot sizes, no cul-de-sacs, walking paths)
Vale and Pereira (2016)	P	P	P				X	- number of walking trips - walking distance	own survey	415	full-time workers and students living and working in one city	2013	Portugal	- building density, density of commercial land use, proximity to transit - density of pedestrian area, area accessible via the street network
Vale et al. (2018)	P	P					X	- commuting mode to university	own survey	1474	students and staff of University of Lisbon	2015	Portugal	- proximity to university - walkability (density of residents and dwellings, land use diversity; link length, area accessible via the street network) - accessibility (access to metro and train station, number of transit stops)
van de Coevering et al. (2016)	P						X	- mode choice	Bohte 2010, own survey	1322	random sample in 3 cities (longitudinal study)	2005, 2012	Netherla-nds	- proximity to railway station
Voulgaris et al. (2017)	P	P	P				X	- mode choice	National Household Travel Survey (NHTS)	72183	census tracts	2009	USA	- dense, transient, accessible urban neighbourhood
Winters et al. (2010)	P, A	P	P, E				X	- likelihood of cycling	Cycling in Cities survey	1902	current and potential cyclists	2006	Canada	- specific land use, land use diversity, population density - intersection density, low percentage of highway or arterial roads - traffic calming features, road markings, signage along bicycle routes
Zegras et al. (2012)	P	P					X	- number of walking or cycling trips within one week	own survey	1859	people born between 1946 and 1964	n. m.	USA	- design aspects of age-restricted neighbourhoods (presence of public spaces or sports facilities, loop street pattern, intersection density, high street length)
Zhang et al. (2014)	P	P					X	- mode choice - trip duration and length	Austin activity travel survey	1423	households inside and outside mixed-use districts	2005	USA	- land use diversity, population and job density

* e.g. georeferenced and census data.
n. m. = not mentioned in the article.
VMT = vehicle miles of travel.

assigned to the emblematic function (E). The selection also includes studies involving several functions at the same time. In the following sections, we will go into more detail regarding this classification.

3.2. Practical function

The practical function refers to the mobility design's effect on travel efforts to reach an activity destination (section 2.2). The built environment might have the impact of reducing or increasing these travel efforts. In terms of non-motorised travel, the practical function is related to the enablement of walking and cycling. Therefore, studies considering evaluations of design elements' effects on travel efforts, such as time requirements, ease of travel and possible barriers, are assigned to the practical function. They primarily comprise assessments with regard to distances, route directness and travel facilitation. Each of the selected studies within this review involves at least one design element with respect to the practical function. Although all types of mobility design elements can be identified, the vast majority (53 out of 56) address land use distribution. Basically, land use sets the proximity to destinations and therefore affects practicability in terms of required time and physical exertion. A particularly comprehensive example is the work of McConville et al. (2011), which analyses 16 different land use types in relation to accessibility (distance from the respondent's home to a certain land use type), intensity (number of instances of certain land use types within an area) and diversity (number of different land use types within an area). The results show that short distances, in particular concerning daily needs destinations, such as grocery stores, restaurants and transit stops, are associated with higher shares of walking. In addition, mixed and compact land use is related to a high extent of walking by favouring proximity. Various studies affirm this positive impact of land use density (28 studies) and diversity (23 studies) on non-motorised travel behaviour (e.g. Aguiléra and Voisin, 2014; Ewing et al., 2013; Gehrke and Clifton, 2014; Hirsch et al., 2016; Vale et al., 2018; Winters et al., 2010; Zhang et al., 2014).

Many of the selected studies (42) also involve practical characteristics of the street network, which constitute directness, coherence and a variety of routes and therefore affect distances and navigation ability. According to 16 studies, a high density of intersections encourages non-motorised travel. For example, the results of Ewing et al. (2013) show that the likelihood of walking increases with intersection density, while car trips decline. Berrigan et al. (2010) include further variables, such as block length and density, as wells as node connectivity, suggesting that grid-like structures can be associated with active transportation (see also Lee et al., 2017; Lindelöw et al., 2017). Overall, four studies identify small parcel or block sizes and three studies the absence of cul-de-sacs as supporting walking or cycling.

Walking and cycling facilities represent a practical design function primarily by protecting, accelerating and facilitating non-motorised movement. 24 studies of the selection consider these elements. Ten studies point out the positive impact of adequate pavements, footpaths and cycling paths (e.g. Larco et al., 2012; Mitra et al., 2015; Stevens and Brown, 2011). Gunn et al. (2014) show this correlation by observing an increase in the proportion of people walking at least 60 minutes per week related to pavement condition status, involving segments providing no pavement at all, one pavement along the street and two pavements along the street. In addition, Moniruzzaman and Páez (2012) identify crossing aids as associated with walking frequency. Kamargianni (2015) provides a good overview of the practical function of cycling facilities. Based on the preferences of more than 9,500 adolescents in five cities in Greece and Cyprus, the author shows that, aside from weather conditions, the presence of cycle paths between origin and destination as well as the availability of bike parking spaces at the destination are the decisive practical function elements which encourage cycling.

Practical public space qualities mainly contribute to safety, convenience and facilitation by providing certain micro-scale elements, only analysed within three of the selected studies. Mitra et al. (2015) detect the absence of benches as the main barrier to elderly people's active transport. By supporting safe movement in public space, adequate streetlights increase the likelihood of walking, a design element also discussed by Moniruzzaman and Páez (2012) and Ramezani et al. (2018).

3.3. Aesthetic function

Design elements contributing to the environment's appearance affecting its perceived attractiveness and evoking feelings of pleasure or displeasure are related to the aesthetic function (Crilly et al., 2004). They comprise order, shape, texture, surface, colour and planting characteristics. Studies investigating individual perceptions of an element's attractiveness or feelings evoked by its characteristics (e.g. by means of in-depth interviews) are assigned to the aesthetic function. As vegetation land use in urban environments is associated with positive feelings and assessments of beauty (section 2.3), also the presence of greenery or parks indicates aesthetic effects. Ten of the studies consider these elements. While Moniruzzaman and Páez (2012), Giles-Corti et al. (2013) and Mitra et al. (2015) found the proximity to greenery land uses positively correlated with walking behaviour, Winters et al. (2010), McConville et al. (2011), Koohsari et al. (2013), Rybarczyk and Wu (2014) and Cho and Rodríguez (2015) did not affirm such a relation.

Few of the selected studies investigate street network configuration in terms of the aesthetic design function (Hajrasouliha and Yin, 2015; Lamíquiz and López-Domínguez, 2015; Rybarczyk and Wu, 2014). They relate to the impact of visual connectivity. In contrast to physical connectivity, defined by geographic distances, visual connectivity refers to the perceived visual distance to a place, primarily depending on the street network's geometry and order. In that sense, nearby destinations requiring changes of direction within the network might appear more distant than further destinations accessible on a straight line. Hajrasouliha and Yin (2015) point out the direct impacts of visual connectivity on walking behaviour – independent of physical connectivity – causing a positive feeling of being "invited to enter a space and feel welcome in it". Rybarczyk and Wu (2014) involve visual entropy and visual depth, emphasising the effects of visual complexity concerning walking and cycling wayfinding. Within design theory, perceived complexity of objects and arrangements represents a basic aesthetic quality, evoking feelings of arousal or pleasantness depending on its characteristics (section 2.2).

None of the selected studies includes the assessment of aesthetical qualities of walking and cycling facilities. Analyses of pavements, crossings or bike lanes, primary focus on the presence or density of these infrastructures. Mitra et al. (2015) address the quality of facilities only in terms of maintenance and physical obstructions, thus also considering the practical rather than the aesthetic design function. In contrast, several studies related to public space quality and related micro-scale design elements can be identified. Giles-Corti et al. (2013) and Koohsari et al. (2013) point out the impact of aesthetical qualities on walking by directly questioning the participants' perception of neighbourhood aesthetics. Milakis et al. (2017) maintain the perception of the "nice architectural design of residential, civic buildings and/or street furniture" as positively associated with cycling. Appleyard (2012) and Moniruzzaman and Páez (2012) analyse aesthetical qualities by means of objective measures, such as parcel geometry and how far a building is set back along with its height, highlighting resultant impressions of enclosure and human scale proportions (cf. Ewing and Clemente, 2013). Without pre-setting certain variables, the in-depth interviews by Mitra et al. (2015) revealed the importance of nice scenery, natural landscapes and other amenities (e.g. fountains, gardens) as respondents described associated positive feelings.

3.4. Emblematic function

From the design theory perspective, the emblematic function is related to the information conveyed by an object, either signifying its handling and operation or evoking certain associations (section 2.2). Studies involving design elements for which such conveyance can be clearly identified or which explicitly consider respective effects (e.g. by including questions in a survey investigating associations with a certain street) are assigned to this function. For the travel-related built environment, elements signifying handling or operation may refer to traffic signals (e.g. street signs, markings and traffic lights pointing out infrastructure utilisation) or traffic reporting (e.g. speed sensors, counting points, countdown signals). Only two of the selected studies deal with these sign elements. Winters et al. (2010) involve a variety of built environment features, also comprising the presence of bicycle-related signs. In consideration of cycling trip zones (origin, route, destination), the authors point out the promoting effects of cyclist-activated traffic lights along routes as well as markings and route signs within the destination zone. Mitra et al. (2015) mention stop signs and gradual curb cuts at an intersection as important hints for pedestrians.

As subjective associations of an environment with certain values, norms or conditions depend on the effects of built components as well as on individual prerequisites, the evaluation of corresponding impacts on non-motorised travel behaviour is challenging. Yet, some of the selected studies address those symbolic contents with regard to associations of safety within certain areas. For instance, Milakis et al. (2017) indicate a correlation between perceived overall biking safety conditions and the likelihood of cycling. The results of Battista and Manaugh (2018), Giles-Corti et al. (2013) and Koohsari et al. (2013) suggest an impact of traffic and crime safety perception concerning the surrounding built environment on walking behaviour. Respondents of Mitra et al. (2015) outline the association with safety, evoked by the presence of micro-scale design elements such as streetlights, security cameras and neighbourhood watch signs. Another approach was adopted by Frank et al. (2015) who base their analysis on a survey with the use of illustrations showing competing development types either symbolising car orientation or walkability. Respondents were supposed to indicate which of the illustrations best represent their own neighbourhood. As people who associated their neighbourhood with a higher degree of walkability showed a higher likelihood of walking, emblematics of the built environment seem to have an impact on behaviour.

4. Consideration of mobility design elements in previous studies: a critical discussion

The analysis of the selected studies with regard to mobility design and its effects on non-motorised travel behaviour gives some key insights into the causal relations of certain factors and the impacts of design on human behaviour in general. However, gaps in previous research can be identified, which we discuss within this section. These include (i) the selection of evaluated design types and functions, (ii) the method of data collection, (iii) the comparability of results, (iv) the examined regions and (v) the impact of other influencing factors.

First of all, most of the studies only refer to the practical effects of design elements (39 out of 56), mainly investigated on the basis of objective characteristics of land use and street network, or the presence of walking and cycling facilities. Therefore, the design's impact on factors of traditional utility theory, such as travel distances and required travel time, are taken into account primarily (Bohte et al., 2009). The aesthetic function (16 studies) as well as the emblematic function (8 studies) receive less attention. They are represented merely by a small number of variables, in part captured by directly inquiring about subjective impressions. Thus, the findings of the impacts related to emotions or symbolic associations are very limited. Furthermore, elements related to the signifier function, affecting the orientation of pedestrian and cyclists or the utilisation of infrastructures only occur in two studies. With regard to the idea of 'human-centred design' creating liveable and attractive spaces and the hypothesised influence of open space quality, architectures and micro-design elements on individual behaviour (cf. Appleyard, 1980; Gehl, 2010; Lawrence and Low, 1990; Stamps, 2011), especially these functions require further research and new methodological approaches (Ewing and Handy, 2009; Timms and Tight, 2010).

One explanation for the focus on practical design impacts might be the reference of many of the reviewed studies to the work of Cervero and Kockelman (1997) on the "3Ds" concept, as it primarily addresses density and diversity of land use, street network patterns and infrastructures in terms of shortening distances and facilitating movement. Also, some of the most citied indexes for walkability only include these kinds of components (e.g. Frank et al., 2009). Another reason might relate to the challenges of data collection. As aesthetic or symbolic assessments might differ from one person to another and are based on the combined effect of a variety of features, partly on a small scale, more elaborated investigation methods are required. However, most of the studies include information on the built environment by referring to secondary georeferenced data obtained from external sources, e.g. census data or parcel data, which have been processed by means of GIS software. Mainly correlations of these data with data on travel behaviour are analysed by means of statistical methods (e.g. regressions) to draw conclusions on the impact of design elements. Partly, aerial photography (Larco et al., 2012; Zhang et al., 2014) and satellite images (Joh et al., 2012; Kamruzzaman et al., 2016; Zegras et al., 2012) as well as the authors' observations on site were used. In order to provide data also involving aesthetic or emblematic qualities, interview survey approaches seem suitable, as these identify subjective perceptions rather than objective characterisations. For example Battista and Manaugh (2018) as well as Mitra et al. (2015) implemented these approaches within their studies. Besides questions about general factors influencing travel behaviour, they included mapping methods providing information on the effects of certain objects of the built environment, certain routes and neighbourhoods. The participants were asked to specify their feelings and associations related to the respective locations and elements. Respective negative perceptions as well as other barriers preventing walking or cycling were added to the maps as were positive effects encouraging non-motorised travel. Another approach for investigating the impact of aesthetic and emblematic functions was implemented by Frank et al. (2015). They analysed their respondents' assessments of several illustrations of open spaces in respect of preferences for walking (section 3.4). Perceptions concerning individual elements can be examined using this method.

Another issue relates to the challenging comparability of the studies' findings due to different study areas and research questions resulting in varying sample characteristics and dependent variables. Several studies focus on walking behaviour only, represented by diverse variables, such as walking frequency including all walking trips or those lasting at least a certain time period, walking duration, walking distance, step count or even the number of pedestrians within an observed street. In some cases, the survey data are also included in demand model evaluations for verification purposes (e.g. Ewing et al., 2013; Moniruzzaman and Páez, 2012). Furthermore, some of the works only consider certain trip purposes or groups of people, for example elderly people (e.g. Hirsch et al., 2016; Moniruzzaman et al., 2013) or students (e.g. Helbich, 2017; Kamargianni, 2015; Stevens and Brown, 2011), who usually have different requirements and attitudes regarding travel and design. In addition, different concepts related to the design elements' spatial frame of reference may affect the comparability of results. As a high number of the studies refers to built environment information that is based on secondary data (e.g. census data), mostly administrative areas represent the spatial frame. Other works relate to the respondent's immediate surroundings, defined as the neighbourhood or set by a spatial buffer of a certain distance (e.g. Lee et al., 2013; Rybarczyk and Wu, 2014). Also, the spatial frame may be associated with different sections of a trip, including home or origin, destination and route (Winters et al., 2010). In order to compare findings from the reviewed studies, all of these different concepts and methods have to be taken into account. In general, equal dependent variables, preferably involving walking and cycling behaviour or mode choice as well as similar sample characteristics simplify interpretations and transferability of results.

Moreover, the papers consider urban spaces in various regions of western society. By far the most studies (34 out of 56) were conducted in North America (USA or Canada). Fifteen refer to Europe, seven to Australia or New Zealand. All of these regions differ in historical developments and path dependencies, which is also reflected in their cities' mobility planning and built environments, in particular manifested in architectures and street network structures. Thus, studies on diverse regions may reveal different results.

Finally, it should be recognised that, aside from mobility design functions, other factors affect non-motorised travel behaviour. For instance, physical limitations may hinder active travel or a low income may prevent the purchase of a car forcing people to walk or cycle. In addition, non-built factors specifying urban environments and mobility cultures should be considered. These comprise city-related regulations, policies, discourses, milieus and social norms (Klinger et al., 2013) as well as individual preferences and attitudes, for example related to different transport modes or environmental issues (e.g. Frank et al., 2015; Kamruzzaman et al., 2016; Ramezani et al., 2018). Residential self-selection processes may occur, implying that people choose their surroundings based on their travel demands, rather than being influenced by these surroundings. In this context, information about relocations (cf. Giles-Corti et al., 2013; van de Coevering et al., 2016) and individual preferences concerning residential choice should be considered (cf. Lindelöw et al., 2017; McCormack et al., 2017; Noland and DiPetrillo, 2015; Zegras et al., 2012).

5. Conclusions

The promotion of non-motorised travel modes is one key element for mitigating the social and environmental effects of motorised traffic (Koska and Rudolph, 2016; Winters et al., 2017). Frequently, the design of the built environment is considered as an important factor for that endeavour (Næss, 2015). The aim of this paper is to contribute to this stream of research by merging a mobility design perspective with 'built environment and travel behaviour' research going beyond traditional utility theory. It is our ambition to provide new insights by discussing the three main functions of mobility design for promoting non-motorised travel: the practical encompasses the enablement, facilitation and safety of walking and cycling; the aesthetic contributes to the perceived attractiveness and appeal of a place; the emblematic evokes symbolic associations or provides signs for interaction with the environment.

Our analysis of 56 recent studies revealed a strong focus of travel behaviour research on the practical function: the proximity to destinations arising from land use distribution, density and diversity; the directness, coherence and variations of routes depending on street network patterns; the presence of facilities dedicated to walking and cycling; as well as the provision of micro-design elements facilitating travel (e.g. benches, lighting). Less attention has been drawn to the aesthetic function in the studies, albeit positive effects of greenery, of high visual connectivity and of the attractiveness of the urban space are mentioned. Ultimately, findings on the impacts of the emblematic design function have been very limited. Only the associations of the built environment with safety and walkability are mentioned as well as the presence of traffic lights and signs.

In our view, design functions provide an improved understanding of the interaction of built environments with cognitive processes and individual decision-making. Thus, the approach may guide further research on the effects of the built environment on non-motorised travel. Since also the aesthetic and emblematic functions exert an impact on travel behaviour, respective research should consider these as well and investigate their actual extent of influence. Especially, hitherto neglected micro-scale elements (e.g. trees and streetlights) indicate aesthetic or emblematic functions, adding interest for further investigations of these. Other identified research shortcomings comprise the use of unsuitable data, the challenging comparability due to varying sample characteristics and dependent variables as well as the impact of non-built influencing factors. In order to evaluate the impacts of mobility design on travel behaviour, techniques for the detection of the respective elements and for the capture of individual perceptions and actions are needed. In our view, it seems useful to not only rely on census data or parcel data, but to involve other methods, such as photography analysis, for example made by Larco et al. (2012) and Mitra et al. (2015). These methods also include certain techniques not mentioned within the selected studies, for instance wearable cameras and sensors capturing point-of-view impressions (cf. Oliver et al., 2013) and LIDAR detecting spatial structures by means of laser sensors (cf. Lindsey et al., 2008). In order to be able to make precise statements on how a certain element influences non-motorised travel behaviour, we recommend qualitative and quantitative survey techniques identifying subjective judgements. As several studies showed, in-depth interviews, mapping methods and illustration assessments identifying individual perceptions of certain design elements contribute to a better understanding of the aesthetic and emblematic functions. As elements might impinge on the user by means of two or three functions simultaneously, a distinction on this point within a survey should be considered. For example, in relation to a certain street segment, its practical usability for reaching destinations (practical function), the feelings evoked by its appearance when passing through (aesthetic function) and the associated contents arising (emblematic function) could be researched. Besides survey methods, the recording of perceptions, feelings and associations could also be implemented during travel directly linked to the current location and its design elements, either automated by means of an app or manually (see e.g. Isomursu et al., 2007).

Certainly, further research is needed on an effective way to detect the functions' impacts. In addition, comparable survey methods and items are necessary. Furthermore, the interaction of mobility design functions with individual attitudes and needs, causalities (e.g. residential self-selection) and non-physical characteristics of the environment (e.g. regulations and policies, social norms or discourses) should be taken into account. These also comprise mobility services that are associated with encouraging sustainable travel, such as sharing systems and apps facilitating seamless mobility (Kamargianni et al., 2016; Ricci, 2015). As we recognised a strong focus on North American urban areas, further research on regions with different development paths and mobility cultures should be considered (Klinger et al., 2013).

Limitations of this review involve the selection of the studies considered. Including additional search terms as well as broadening the evaluation period would have resulted in a higher number of matches, allowing a more comprehensive view of design elements and functions taken into account up to the present day. In addition, a specific search for techniques to detect design elements or for demand models analysing impact on behaviour could have revealed further implications for possible methodologies. However, previous reviews on this topic (e.g. Ewing and Cervero, 2010; Saelens and Handy, 2008) suggest overall emphases similar to our findings. Another limitation of this review is related to the comparability of the studies' results due to the omission of respective effect size values. Thus, it is not possible to determine which elements are more effective with regard to the promotion of non-motorised travel. The reason for this is the variety of methods used within the selected studies that do not always provide statistically significant values, in particular qualitative survey data. However, such precise effect sizes are of interest especially in terms of design element implementations and interventions. So, they are a relevant issue for further research.

Declaration of Competing Interest

None

Acknowledgements

This work has been funded by the LOEWE research funding program of the German State of Hesse as part of the LOEWE research cluster „Infrastructure – Design – Society“. The authors would like to thank Alison Hindley Chatterjee for proofreading the first version of this paper.

References

Aguiléra, A., Voisin, M., 2014. Urban form, commuting patterns and CO2 emissions: what differences between the municipality's residents and its jobs? Transp. Res. A Policy Pract. 69, 243–251. https://doi.org/10.1016/j.tra.2014.07.012.

Appleyard, D., 1980. Livable Streets: Protected Neighborhoods? Ann. Am. Acad. Polit. Social Sci. 451, 106–117. https://doi.org/10.1177/000271628045100111.

Appleyard, B., 2012. Sustainable and healthy travel choices and the built environment: analyses of green and active access to rail transit stations along individual corridors. Transp. Res. Rec. 2303 (1), 38–45. https://doi.org/10.3141/2303-05.

Appleyard, B.S., Ferrell, C.E., 2017. The Influence of crime on active & sustainable travel: new geo-statistical methods and theories for understanding crime and mode choice. J. Transp. Health 6, 516–529. https://doi.org/10.1016/j.jth.2017.04.002.

Arida, A., 2007. In: Erlhoff, M., Marshall, T. (Eds.), Design Dictionary. Perspectives on Design Terminology. Walter de Gruyter, Basel/Berlin/Boston, pp. 422–424 Urban Design.

Badland, H.M., Oliver, M., Kearns, R.A., Mavoa, S., Witten, K., Duncan, M.J., Batty, G.D., 2012. Association of neighbourhood residence and preferences with the built environment, work-related travel behaviours, and health implications for employed adults: Findings from the URBAN study. Soc. Sci. Med. 75, 1469–1476. https://doi.org/10.1016/j.socscimed.2012.05.029.

Banerjee, U., Hine, J., 2014. Identifying the underlying constructs linking urban form and travel behaviour using a grounded theory approach. Int. J. Environ. Sci. Technol. 11 (8), 2217–2232. https://doi.org/10.1007/s13762-014-0585-0.

Banister, D., 2008. The sustainable mobility paradigm. Transp. Policy 15 (2), 73–80. https://doi.org/10.1016/j.tranpol.2007.10.005.

Banister, D., Hickman, R., 2006. How to design a more sustainable and fairer built environment: Transport and communications. IEE Proce. - Intel. Transp. Syst. 153 (4), 276–291. https://doi.org/10.1049/ip-its:20060009.

Barnes, R., Winters, M., Ste-Marie, N., McKay, H., Ashe, M.C., 2016. Age and retirement status differences in associations between the built environment and active travel behaviour. J. Transp. Health 3 (4), 513–522. https://doi.org/10.1016/j.jth.2016.03.003.

Battista, G.A., Manaugh, K., 2018. Stores and mores: toward socializing walkability. J. Transp. Geogr. 67, 53–60. https://doi.org/10.1016/j.jtrangeo.2018.01.004.

Berrigan, D., Pickle, L.W., Dill, J., 2010. Associations between street connectivity and active transportation. Int. J. Health Geogr. 9, 20–37. https://doi.org/10.1186/1476-072X-9-20.

Bhat, C., Handy, S., Kockelman, K., Mahmassani, H., Chen, Q., Weston, L., 2000. Accessibility Measures: Formulation Considerations and Current Applications. Research Report 4938-2. Center for Transportation Research, University of Texas, Austin.

Bohte, W., Maat, K., van Wee, B., 2009. Measuring attitudes in research on residential self-selection and travel behaviour: a review of theories and empirical research. Transp. Rev. 29 (3), 325–357. https://doi.org/10.1080/01441640902808441.

Börjesson, M., Hamilton, C.J., Näsman, P., Papaix, C., 2015. Factors driving public support for road congestion reduction policies: congestion charging, free public transport and more roads in Stockholm, Helsinki and Lyon. Transp. Res. A Policy Pract. 78, 452–462. https://doi.org/10.1016/j.tra.2015.06.008.

Brownson, R.C., Hoehner, C.M., Day, K., Forsyth, A., Sallis, J.F., 2009. Measuring the built environment for physical activity: state of the science. Am. J. Prev. Med. 36 (4 Suppl). https://doi.org/10.1016/j.amepre.2009.01.005. S99-123.e12.

Bürdek, B.E., 2015. Design: History, Theory and Practice of Product Design, 2nd ed. Birkhäuser: Basel.

Cervero, R., 2003. The built environment and travel: Evidence from the United States. Eur. J. Transp. Infrastruct. Res. 3 (2), 119–137.

Cervero, R., Kockelman, K., 1997. Travel demand and the 3Ds: density, diversity and design. Transp. Res. Part D: Transp. Environ. 2 (3), 199–219. https://doi.org/10.1016/S1361-9209(97)00009-6.

Cho, G.-H., Rodríguez, D.A., 2015. Neighborhood design, neighborhood location, and three types of walking: results from the Washington DC Area. Environ. Plann. B 42 (3), 526–540. https://doi.org/10.1068/b130222p.

Crane, R., 2000. The influence of urban form on travel: an interpretive review. J. Plan. Lit. 15 (1), 3–23. https://doi.org/10.1177/08854120022092890.

Crilly, N., Moultrie, J., Clarkson, P.J., 2004. Seeing things: consumer response to the visual domain in product design. Des. Stud. 25 (6), 547–577. https://doi.org/10.1016/j.destud.2004.03.001.

Cui, Y., Mishra, S., Welch, T.F., 2014. Land use effects on bicycle ridership: a framework for state planning agencies. J. Transp. Geogr. 41, 220–228. https://doi.org/10.1016/j.jtrangeo.2014.10.004.

Curl, A., Kearns, A., Macdonald, L., Mason, P., Ellaway, A., 2018. Can walking habits be encouraged through area-based regeneration and relocation?: a longitudinal study of deprived communities in Glasgow, UK. J. Transp. Health 10, 44–55. https://doi.org/10.1016/j.jth.2018.06.004.

de Vos, J., Ettema, D., Witlox, F., 2018. Changing travel behaviour and attitudes following a residential relocation. J. Transp. Geogr. 73, 131–147. https://doi.org/10.1016/j.jtrangeo.2018.10.013.

Demirbilek, O., Sener, B., 2003. Product design, semantics and emotional response. Ergonomics 46 (13-14), 1346–1360. https://doi.org/10.1080/00140130310001610874.

Edelmann, T., 2007. In: Erlhoff, M., Marshall, T. (Eds.), Design Dictionary. Perspectives on Design Terminology. Walter de Gruyter, Basel/Berlin/Boston, pp. 259–261 Mobility.

Ewing, R., Cervero, R., 2010. Travel and the Built Environment. J. Am. Plan. Assoc. 76 (3), 265–294. https://doi.org/10.1080/01944361003766766.

Ewing, R., Clemente, O., 2013. Measuring urban design: metrics for livable places. Island Press Washington D.C.

Ewing, R., Handy, S., 2009. Measuring the unmeasurable: urban design qualities related to walkability. J. Urban Des. 14 (1), 65–84. https://doi.org/10.1080/13574800802451155.

Ewing, R., Greenwald, M.J., Zhang, M., Bogaerts, M., Greene, W., 2013. Predicting transportation outcomes for LEED projects. J. Plan. Educ. Res. 33 (3), 265–279. https://doi.org/10.1177/0739456X13482978.

Flade, A., 2013. Der rastlose Mensch: Konzepte und Erkenntnisse der Mobilitätspsychologie. Springer VS, Wiesbaden.

Frank, L.D., Engelke, P.O., 2001. The built environment and human activity patterns: exploring the impacts of urban form on public health. J. Plan. Lit. 16 (2), 202–218. https://doi.org/10.1177/08854120122093339.

Frank, L.D., Sallis, J.F., Saelens, B.E., Leary, L., Cain, K., Conway, T.L., Hess, P.M., 2009. The development of a walkability index: application to the neighborhood quality of life study. Br. J. Sports Med. 44 (13), 924–933. https://doi.org/10.1136/bjsm.2009.058701.

Frank, L.D., Kershaw, S.E., Chapman, J.E., Campbell, M., Swinkels, H.M., 2015. The unmet demand for walkability: Disparities between preferences and actual choices for residential environments in Toronto and Vancouver. Can. J. Public Health 106 (1), 12–20. https://doi.org/10.17269/cjph.106.4397.

Franz, G., Wiener, J.M., 2008. From space syntax to space semantics: a behaviorally and perceptually oriented methodology for the efficient description of the geometry and topology of environments. Environ. Plann. B 35 (4), 574–592. https://doi.org/10.1068/b33050.

Frey, H., 1999. Designing the City. Routledge, London.

Gehl, J., 2010. Cities for People. Island Press, Washington D.C.

Gehrke, S.R., Clifton, K.J., 2014. Operationalizing land use diversity at varying geographic scales and its connection to mode choice. Transp. Res. Rec. 2453 (1), 128–136. https://doi.org/10.3141/2453-16.

Gehrke, S.R., Welch, T.F., 2017. The built environment determinants of activity participation and walking near the workplace. Transportation 44 (5), 941–956. https://doi.org/10.1007/s11116-016-9687-5.

Geurs, K.T., van Wee, B., 2004. Accessibility evaluation of land-use and transport strategies: Review and research directions. J. Transp. Geogr. 12, 127–140. https://doi.org/10.1016/j.jtrangeo.2003.10.005.

Giacomin, J., 2015. What Is Human Centred Design? Des. J. 17 (4), 606–623. https://doi.org/10.2752/175630614X14056185480186.

Gibson, J.J., 1979. The Ecological Approach to Visual Perception. Boston, Houghton Mifflin.

Giles-Corti, B., Bull, F., Knuiman, M., McCormack, G., van Niel, K., Timperio, A., Christian, H., Foster, S., Divitini, M., Middleton, N., Boruff, B., 2013. The influence of urban design on neighbourhood walking following residential relocation: longitudinal results from the RESIDE study. Soc. Sci. Med. 77, 20–30. https://doi.org/10.1016/j.socscimed.2012.10.016.

Godau, M., 2003. Produktdesign: Eine Einführung mit Beispielen aus der Praxis. Birkhäuser: Basel.

Gros, J., 1972. Empirische Ästhetik. Staatliche Hochschule für Bildende Künste Braunschweig.

Gros, J., 1983. Grundlagen einer Theorie der Produktsprache: Einführung. Hochschule für Gestaltung Offenbach am Main.

Gunn, L.D., Lee, Y., Geelhoed, E., Shiell, A., Giles-Corti, B., 2014. The cost-effectiveness of installing sidewalks to increase levels of transport-walking and health. Prev. Med. 67, 322–329. https://doi.org/10.1016/j.ypmed.2014.07.041.

Hajrasouliha, A., Yin, L., 2015. The impact of street network connectivity on pedestrian volume. Urban Stud. 52 (13), 2483–2497. https://doi.org/10.1177/0042098014544763.

Handy, S., 2018. Enough with the "D's" Already - Let's Get Back to "A" Transf. Magazine 1 (1), 24–26.

Handy, S.L., Boarnet, M.G., Ewing, R., Killingsworth, R.E., 2002. How the built environment affects physical activity: views from Urban Planning. Am. J. Prev. Med. 23 (2), 64–73. https://doi.org/10.1016/S0749-3797(02)00475-0.

Helbich, M., 2017. Children's school commuting in the Netherlands: Does it matter how urban form is incorporated in mode choice models? Int. J. Sustain. Transp. 11 (7), 507–517. https://doi.org/10.1080/15568318.2016.1275892.

Hirsch, J.A., Winters, M., Ashe, M.C., Clarke, P., McKay, H., 2016. Destinations that older adults experience within their GPS activity spaces: relation to objectively measured physical activity. Environ. Behav. 48 (1), 55–77. https://doi.org/10.1177/0013916515607312.

Holtzclaw, J., 1994. Using Residential Patterns and Transit to Decrease Auto Dependence

and Costs. Natural Resources Defense Council, San Francisco.
Hong, J., Shen, Q., Zhang, L., 2014. How do built-environment factors affect travel behavior?: A spatial analysis at different geographic scales. Transportation 41 (3), 419–440. https://doi.org/10.1007/s11116-013-9462-9.
Hong, A., Boarnet, M.G., Houston, D., 2016. New light rail transit and active travel: a longitudinal study. Transp. Res. A Policy Pract. 92, 131–144. https://doi.org/10.1016/j.tra.2016.07.005.
Isomursu, M., Tähti, M., Väinämö, S., Kuutti, K., 2007. Experimental evaluation of five methods for collecting emotions in field settings with mobile applications. Int. J. Hum.-Comput. Stud. 65 (4), 404–418. https://doi.org/10.1016/j.ijhcs.2006.11.007.
Jensen, O.B., 2014. Designing Mobilities. Aalborg University Press, Aalborg.
Jensen, O.B., Lanng, D.B., Wind, S., 2016. Mobilities design – towards a research agenda for applied mobilities research. Appl. Mobil. 1 (1), 26–42. https://doi.org/10.1080/23800127.2016.1147782.
Joh, K., Nguyen, M.T., Boarnet, M.G., 2012. Can built and social environmental factors encourage walking among individuals with negative walking attitudes? J. Plan. Educ. Res. 32 (2), 219–236. https://doi.org/10.1177/0739456X11427914.
Johansson, M., Sternudd, C., Kärrholm, M., 2016. Perceived urban design qualities and affective experiences of walking. J. Urban Des. 21 (2), 256–275. https://doi.org/10.1080/13574809.2015.1133225.
Kamargianni, M., 2015. Investigating next generation's cycling ridership to promote sustainable mobility in different types of cities. Res. Transp. Econ. 53, 45–55. https://doi.org/10.1016/j.retrec.2015.10.018.
Kamargianni, M., Li, W., Matyas, M., Schäfer, A., 2016. A critical review of new mobility services for urban transport. Transp. Res. Proc. 14, 3294–3303. https://doi.org/10.1016/j.trpro.2016.05.277.
Kamruzzaman, M., Washington, S., Baker, D., Brown, W., Giles-Corti, B., Turrell, G., 2016. Built environment impacts on walking for transport in Brisbane, Australia. Transportation 43 (1), 53–77. https://doi.org/10.1007/s11116-014-9563-0.
Kim, D., Park, J., Hong, A., 2018. The role of destination's built environment on non-motorized travel behavior: a case of long beach, California. J. Plan. Educ. Res. 38 (2), 152–166. https://doi.org/10.1177/0739456X16688765.
Klinger, T., Kenworthy, J.R., Lanzendorf, M., 2013. Dimensions of urban mobility cultures – a comparison of German cities. J. Transp. Geogr. 31, 18–29. https://doi.org/10.1016/j.jtrangeo.2013.05.002.
Knuiman, M.W., Christian, H.E., Divitini, M.L., Foster, S.A., Bull, F.C., Badland, H.M., Giles-Corti, B., 2014. A longitudinal analysis of the influence of the neighborhood built environment on walking for transportation: the RESIDE study. Am. J. Epidemiol. 180 (5), 453–461. https://doi.org/10.1093/aje/kwu171.
Koohsari, M.J., Karakiewicz, J.A., Kaczynski, A.T., 2013. Public open space and walking. Environ. Behav. 45 (6), 706–736. https://doi.org/10.1177/0013916512440876.
Koska, T., Rudolph, F., 2016. The role of walking and cycling in reducing congestion: a portfolio of measures. FLOW Project, European Union, Brussels. http://www.h2020-flow.eu, Accessed date: 25 July 2019.
Krippendorff, K., 2006. The Semantic Turn: A New Foundation for Design. CRC/Taylor & Francis, Boca Raton.
Krippendorff, K., Butter, R., 1984. Product semantics: exploring the symbolic qualities of form. Innovation 3 (2), 4–9.
Lamíquiz, P.J., López-Domínguez, J., 2015. Effects of built environment on walking at the neighbourhood scale. A new role for street networks by modelling their configurational accessibility? Transp. Res. A Policy Pract. 74, 148–163. https://doi.org/10.1016/j.tra.2015.02.003.
Lanzendorf, M., Busch-Geertsema, A., 2014. The cycling boom in large German cities—Empirical evidence for successful cycling campaigns. Transp. Policy 36, 26–33. https://doi.org/10.1016/j.tranpol.2014.07.003.
Larco, N., Steiner, B., Stockard, J., West, A., 2012. Pedestrian-friendly environments and active travel for residents of multifamily housing. Environ. Behav. 44 (3), 303–333. https://doi.org/10.1177/0013916511402061.
Lawrence, D.L., Low, S.M., 1990. The built environment and spatial form. Annu. Rev. Anthropol. 19 (1), 453–505.
Lee, J., 2016. Impact of neighborhood walkability on trip generation and trip chaining: case of Los Angeles. J. Urb. Plann. Dev. 142 (3), 1–11. https://doi.org/10.1061/(ASCE)UP.1943-5444.0000312.
Lee, J.S., Zegras, P.C., Ben-Joseph, E., 2013. Safely active mobility for urban baby boomers: The role of neighborhood design. Accid. Anal. Prev. 61, 153–166. https://doi.org/10.1016/j.aap.2013.05.008.
Lee, J., He, S.Y., Sohn, D.W., 2017. Potential of converting short car trips to active trips: The role of the built environment in tour-based travel. J. Transp. Health 7, 134–148. https://doi.org/10.1016/j.jth.2017.08.008.
Lindelöw, D., Svensson, Å., Brundell-Freij, K., Winslott Hiselius, L., 2017. Satisfaction or compensation?: The interaction between walking preferences and neighbourhood design. Transp. Res. Part D: Transp. Environ. 50, 520–532. https://doi.org/10.1016/j.trd.2016.11.021.
Lindsey, G., Wilson, J., Anne Yang, J., Alexa, C., 2008. Urban greenways, trail characteristics and trail use: implications for design. J. Urban Des. 13 (1), 53–79. https://doi.org/10.1080/13574800701804033.
Litman, T., Steele, R., 2018. Land Use Impacts on Transport: How Land Use Factors Affect Travel Behavior. Victoria Transport Policy Institute.
Liu, C., Shen, Q., 2011. An empirical analysis of the influence of urban form on household travel and energy consumption. Comput. Environ. Urban. Syst. 35 (5), 347–357. https://doi.org/10.1016/j.compenvurbsys.2011.05.006.
Maat, K., van Wee, B., Stead, D., 2016. Land use and travel behaviour: expected effects from the perspective of utility theory and activity-based theories. Environ. Plann. B 32 (1), 33–46. https://doi.org/10.1068/b31106.
Mareis, C., 2011. Design als Wissenskultur: Interferenzen zwischen Design- und Wissensdiskursen seit 1960. transcript: Bielefeld.
Mareis, C., 2014. Theorien des Designs zur Einführung. Hamburg, Junius.
Marquet, O., Miralles-Guasch, C., 2015. Neighbourhood vitality and physical activity among the elderly: The role of walkable environments on active ageing in Barcelona, Spain. Soc. Sci. Med. 135, 24–30. https://doi.org/10.1016/j.socscimed.2015.04.016.
Mayer, S., 1996. Wettbewerbsfaktor Design: Zum Einsatz von Design im Markt für Investitionsgüter. Steuer- und Wirtschaftsverlag, Hamburg.
McConville, M.E., Rodríguez, D.A., Clifton, K., Cho, G., Fleischhacker, S., 2011. Disaggregate land uses and walking. Am. J. Prev. Med. 40 (1), 25–32. https://doi.org/10.1016/j.amepre.2010.09.023.
McCormack, G.R., Shiell, A., 2011. In search of causality: A systematic review of the relationship between the built environment and physical activity among adults. Int. J Behav. Nutri. Physical Activ. 8, 125. https://doi.org/10.1186/1479-5868-8-125.
McCormack, G.R., McLaren, L., Salvo, G., Blackstaffe, A., 2017. Changes in Objectively-Determined Walkability and Physical Activity in Adults: A Quasi-Longitudinal Residential Relocation Study. Int. J. Environ. Res. Public Health 14 (5). https://doi.org/10.3390/ijerph14050551.
Milakis, D., Efthymiou, D., Antoniou, C., 2017. Built environment, travel attitudes and travel behaviour: quasi-longitudinal analysis of links in the case of Greeks relocating FROM US to Greece. Sustainability 9 (10), 1–17. https://doi.org/10.3390/su9101774.
Mitchell, C.T., 1993. Redefining Design: From Form to Experience. Van Nostrand Reinhold, New York.
Mitra, R., Siva, H., Kehler, M., 2015. Walk-friendly suburbs for older adults? Exploring the enablers and barriers to walking in a large suburban municipality in Canada. J. Aging Stud. 35, 10–19. https://doi.org/10.1016/j.jaging.2015.07.002.
Moniruzzaman, M., Páez, A., 2012. A model-based approach to select case sites for walkability audits. Health Place 18 (6), 1323–1334. https://doi.org/10.1016/j.healthplace.2012.09.013.
Moniruzzaman, M., Páez, A., Nurul Habib, K.M., Morency, C., 2013. Mode use and trip length of seniors in Montreal. J. Transp. Geogr. 30, 89–99. https://doi.org/10.1016/j.jtrangeo.2013.03.007.
Morgan, J., Talbot, R., 2000. Sustainable Social Housing for no Extra Cost? In: Williams, K. (Ed.), Achieving Sustainable Urban Form. Spon, pp. 319–328 London.
Morton, C., Lovelace, R., Anable, J., 2017. Exploring the effect of local transport policies on the adoption of low emission vehicles: evidence from the London Congestion Charge and Hybrid Electric Vehicles. Transp. Policy 60, 34–46. https://doi.org/10.1016/j.tranpol.2017.08.007.
Næss, P., 2005. Residential location affects travel behavior—but how and why?: the case of Copenhagen metropolitan area. Prog. Plan. 63 (2), 167–257. https://doi.org/10.1016/j.progress.2004.07.004.
Næss, P., 2012. Urban form and travel behavior: experience from a Nordic context. J. Transp. Land Use 5 (2), 21–45. https://doi.org/10.5198/jtlu.v5i2.314.
Næss, P., 2015. Built Environment, Causality and Travel. Transp. Rev. 35 (3), 275–291. https://doi.org/10.1080/01441647.2015.1017751.
Næss, P., Sandberg, S.L., Røe, P.G., 1996. Energy use for transportation in 22 Nordic towns. Scand. Housing Plann. Res. 13 (2), 79–97. https://doi.org/10.1080/02815739608730401.
Nasar, J.L. (Ed.), 1992. Environmental Aesthetics: Theory, Research and Applications, 1st ed. Cambridge University Press, Cambridge.
Newman, P., Kenworthy, J., 2006. Urban design to reduce automobile dependence. Opolis 2 (1), 35–52.
Noland, R.B., DiPetrillo, S., 2015. Transit-oriented development and the frequency of modal use. J. Transp. Land Use 8 (2), 21–44. https://doi.org/10.5198/jtlu.2015.517.
Norman, D.A., 1988. The Psychology of everYday Things. Basic Books, New York.
Norman, D.A., 2013. The Design of Everyday Things. Basic Books, New York.
Ogilvie, D., Foster, C.E., Rothnie, H., Cavill, N., Hamilton, V., Fitzsimons, C.F., Mutrie, N., 2007. Interventions to promote walking: Systematic review. BMJ (Clinical research ed.) 334 (7605), 1204. https://doi.org/10.1136/bmj.39198.722720.BE.
Olaru, D., Smith, B., Taplin, J.H.E., 2011. Residential location and transit-oriented development in a new rail corridor. Transp. Res. A Policy Pract. 45 (3), 219–237. https://doi.org/10.1016/j.tra.2010.12.007.
Oliver, M., Doherty, A.R., Kelly, P., Badland, H.M., Mavoa, S., Shepherd, J., Kerr, J., Marshall, S., Hamilton, A., Foster, C., 2013. Utility of passive photography to objectively audit built environment features of active transport journeys: An observational study. Int. J. Health Geogr. 12 (20), 1–7. https://doi.org/10.1186/1476-072X-12-20.
Piatkowski, D.P., Marshall, W.E., Krizek, K.J., 2019. Carrots versus sticks: assessing intervention effectiveness and implementation challenges for active transport. J. Plan. Educ. Res. 39 (1), 50–64. https://doi.org/10.1177/0739456X17715306.
Pikora, T., Giles-Corti, B., Bull, F., Jamrozik, K., Donovan, R., 2003. Developing a framework for assessment of the environmental determinants of walking and cycling. Soc. Sci. Med. 56 (8), 1693–1703. https://doi.org/10.1016/S0277-9536(02)00163-6.
Pucher, J., Dijkstra, L., 2003. Promoting safe walking and cycling to improve public health: Lessons from The Netherlands and Germany. Am. J. Public Health 93 (9), 1509–1516. https://doi.org/10.2105/AJPH.93.9.1509.
Ramezani, S., Pizzo, B., Deakin, E., 2018. An integrated assessment of factors affecting modal choice: Towards a better understanding of the causal effects of built environment. Transportation 45 (5), 1351–1387. https://doi.org/10.1007/s11116-017-9767-1.
Rammler, S., 2003. "Vom Think Tank zum Do Tank – und zurück": Transportation Design als wissenschaftlich basierte Gestaltung zukunftsfähiger Verkehrssysteme. In: Arndt, W.-H. (Ed.), Beiträge aus Verkehrsplanungstheorie und -praxis. [Referate im Rahmen des Kolloquiums "Verkehrsplanungsseminar 2002 und 2003" des Fachgebietes Integrierte Verkehrsplanung des Instituts für Land- und Seeverkehr der Technischen Universität Berlin]. TU, Univ.-Bibliothek, Abt. Publ, pp. 121–137 Berlin.
Rammler, S., 2011. Verkehr und Gesellschaft: Verkehrspolitik als Mobilitätsdesign. In:

Schwedes, O. (Ed.), Verkehrspolitik. Eine interdisziplinäre Einführung. VS Verlag für Sozialwissenschaften: Wiesbaden, pp. 37–55.
Rapoport, A., 1990. The Meaning of the Built Environment: A Nonverbal Communication Approach. University of Arizona Press.
Ricci, M., 2015. Bike sharing: A review of evidence on impacts and processes of implementation and operation. Res. Transp. Bus. Manag. 15, 28–38. https://doi.org/10.1016/j.rtbm.2015.03.003.
Rybarczyk, G., Wu, C., 2014. Examining the Impact of Urban Morphology on Bicycle Mode Choice. Environ. Plann. B 41 (2), 272–288. https://doi.org/10.1068/b37133.
Saelens, B.E., Handy, S.L., 2008. Built environment correlates of walking: A review. Med. Sci. Sports Exerc. 40 (7 Suppl), S550–S566. https://doi.org/10.1249/MSS.0b013e31817c67a4.
Saelens, B.E., Sallis, J.F., Frank, L.D., 2003. Environmental correlates of walking and cycling: Findings from the transportation, urban design, and planning literatures. Ann. Behav. Med. 25 (2), 80–91. https://doi.org/10.1207/S15324796ABM2502_03.
Scheiner, J., 2007. Mobility biographies: Elements of a biographical theory of travel demand. Erdkunde 61, 161–173.
Schneider, B., 2005. Design - eine Einführung: Entwurf im sozialen, kulturellen und wirtschaftlichen Kontext. Basel, Birkhäuser.
Schwer, T. (Ed.), 2014. Produktsprachen: Design zwischen Unikat und Industrieprodukt. Zugl.: Essen, Folkwang-Hochsch., Diss., 2013 u.d.T.: Schwer, Thilo: Evolution der Produktsprache - zwischen seriellem und individuellem Produkt. transcript, Bielefeld.
Siebertz, M., 2007. In: Erlhoff, M., Marshall, T. (Eds.), Design Dictionary. Perspectives on Design Terminology. Walter de Gruyter, Basel/Berlin/Boston, pp. 318–319 Public Design.
Simons, D., de Bourdeaudhuij, I., Clarys, P., de Geus, B., Vandelanotte, C., van Cauwenberg, J., Deforche, B., 2017. Choice of transport mode in emerging adulthood: Differences between secondary school students, studying young adults and working young adults and relations with gender, SES and living environment. Transp. Res. A Policy Pract. 103, 172–184. https://doi.org/10.1016/j.tra.2017.05.016.
Simpson, P., 2017. A sense of the cycling environment: Felt experiences of infrastructure and atmospheres. Environ. Plan. A 49 (2), 426–447. https://doi.org/10.1177/0308518X16669510.
Smardon, R.C., 1988. Perception and aesthetics of the urban environment: Review of the role of vegetation. Landsc. Urban Plan. 15 (1–2), 85–106. https://doi.org/10.1016/0169-2046(88)90018-7.
Smith, M., Hosking, J., Woodward, A., Witten, K., MacMillan, A., Field, A., Baas, P., Mackie, H., 2017. Systematic literature review of built environment effects on physical activity and active transport - an update and new findings on health equity. Int. J Behav. Nutri. Physical Activ. 14 (158), 1–27. https://doi.org/10.1186/s12966-017-0613-9.
Stamps, A.E., 2011. Psychology and the Aesthetics of the Built enviRonment. Springer, New York, London.
Steffen, D., 2000. Design als Produktsprache: Der "Offenbacher Ansatz" in Theorie und Praxis. form: Frankfurt am Main.
Stevens, R.B., Brown, B.B., 2011. Walkable new urban LEED_Neighborhood-Development (LEED-ND) community design and children's physical activity: Selection, environmental, or catalyst effects? Int. J Behav. Nutri. Physical Activ. 8 (139), 1–10. https://doi.org/10.1186/1479-5868-8-139.
Sullivan, L.H., 1896. The tall office building artistically considered. Lippincott's Magazine 57, 403–409.
Timms, P., Tight, M., 2010. Aesthetic aspects of walking and cycling. Built Environ. 36 (4), 487–503. https://doi.org/10.2148/benv.36.4.487.
Vale, D.S., Pereira, M., 2016. Influence on pedestrian commuting behavior of the built environment surrounding destinations: A structural equations modeling approach. Int. J. Sustain. Transp. 10 (8), 730–741. https://doi.org/10.1080/15568318.2016.1144836.
Vale, D.S., Pereira, M., Viana, C.M., 2018. Different destination, different commuting pattern?: Analyzing the influence of the campus location on commuting. J. Transp. Land Use 11 (1), 1–18. https://doi.org/10.5198/jtlu.2018.1048.
van Acker, V., van Wee, B., Witlox, F., 2010. When transport geography meets social psychology: toward a conceptual model of travel behaviour. Transp. Rev. 30 (2), 219–240. https://doi.org/10.1080/01441640902943453.
van de Coevering, P., Maat, K., Kroesen, M., van Wee, B., 2016. Causal effects of built environment characteristics on travel behaviour: a longitudinal approach. Eur. J. Transp. Infrastruct. Res. 16 (4), 674–697. https://doi.org/10.18757/EJTIR.2016.16.4.3165.
van Wee, B., 2002. Land use and transport: Research and policy challenges. J. Transp. Geogr. 10 (4), 259–271. https://doi.org/10.1016/S0966-6923(02)00041-8.
Voulgaris, C.T., Taylor, B.D., Blumenberg, E., Brown, A., Ralph, K., 2017. Synergistic neighborhood relationships with travel behavior: an analysis of travel in 30,000 US neighborhoods. J. Transp. Land Use 10 (1), 437–461. https://doi.org/10.5198/jtlu.2016.840.
Wegener, M., Fürst, F., 1999. Land-Use Transport Interaction: State of the Art. Berichte aus dem Institut für Raumplanung 46. Universität Dortmund - Fakultät Raumplanung: Dortmund.
White, E.V., Gatersleben, B., 2011. Greenery on residential buildings: does it affect preferences and perceptions of beauty? J. Environ. Psychol. 31 (1), 89–98. https://doi.org/10.1016/j.jenvp.2010.11.002.
Winters, M., Brauer, M., Setton, E.M., Teschke, K., 2010. Built environment influences on healthy transportation choices: bicycling versus driving. J. Urban Health 87 (6), 969–993. https://doi.org/10.1007/s11524-010-9509-6.
Winters, M., Buehler, R., Götschi, T., 2017. Policies to promote active travel: evidence from reviews of the literature. Current Environ. Health Rep. 4 (3), 278–285. https://doi.org/10.1007/s40572-017-0148-x.
You, H., Kuohsiang, Chen, 2003. A comparison of affordance concepts and product semantics. In: Asian Design Conference.
Zegras, C., Lee, J.S., Ben-Joseph, E., 2012. By community or design?: age-restricted neighbourhoods, physical design and baby boomers' local travel behaviour in Suburban Boston, US. Urban Stud. 49 (10), 2169–2198. https://doi.org/10.1177/0042098011429485.
Zeh, N., 2017. Erfolgsfaktor Produktdesign. epubli: Berlin.
Zhang, M., Pang, H., Kone, A., 2014. Bridging the gap between the new urbanist ideas and transportation planning practice. Transp. Res. Rec. 2453 (1), 109–117. https://doi.org/10.3141/2453-14.